



... for a brighter future



CO₂ capture and sequestration: Technology options for new and retrofit applications

2nd U.S.-China CO₂ Emissions Control

Science & Technology Symposium

Organized by Zhejiang University and Columbia University

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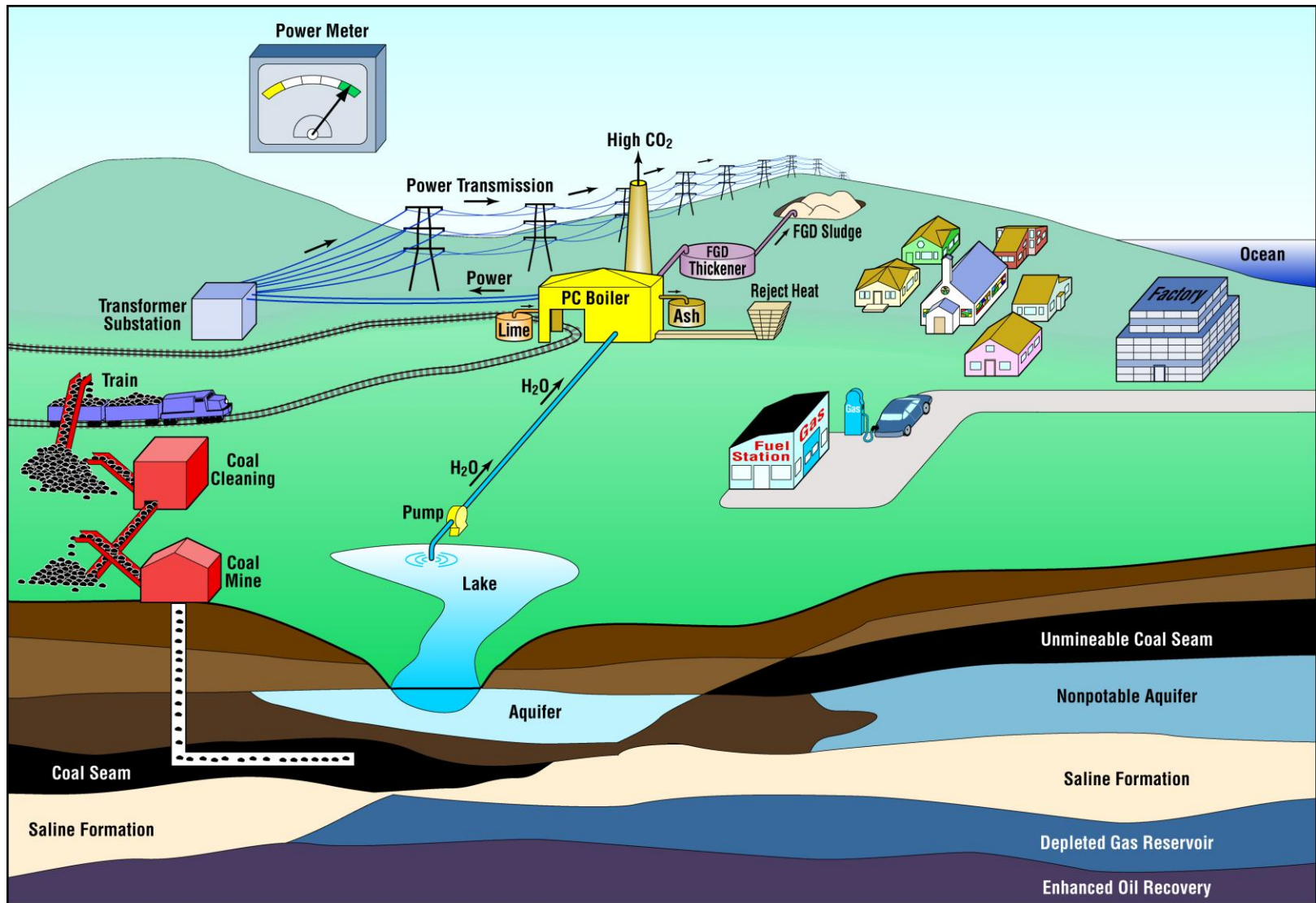
U.S. Department of Energy
Office of Fossil Energy
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Supporting the United Nations IPCC “Special Report” on Carbon Dioxide Capture and Storage

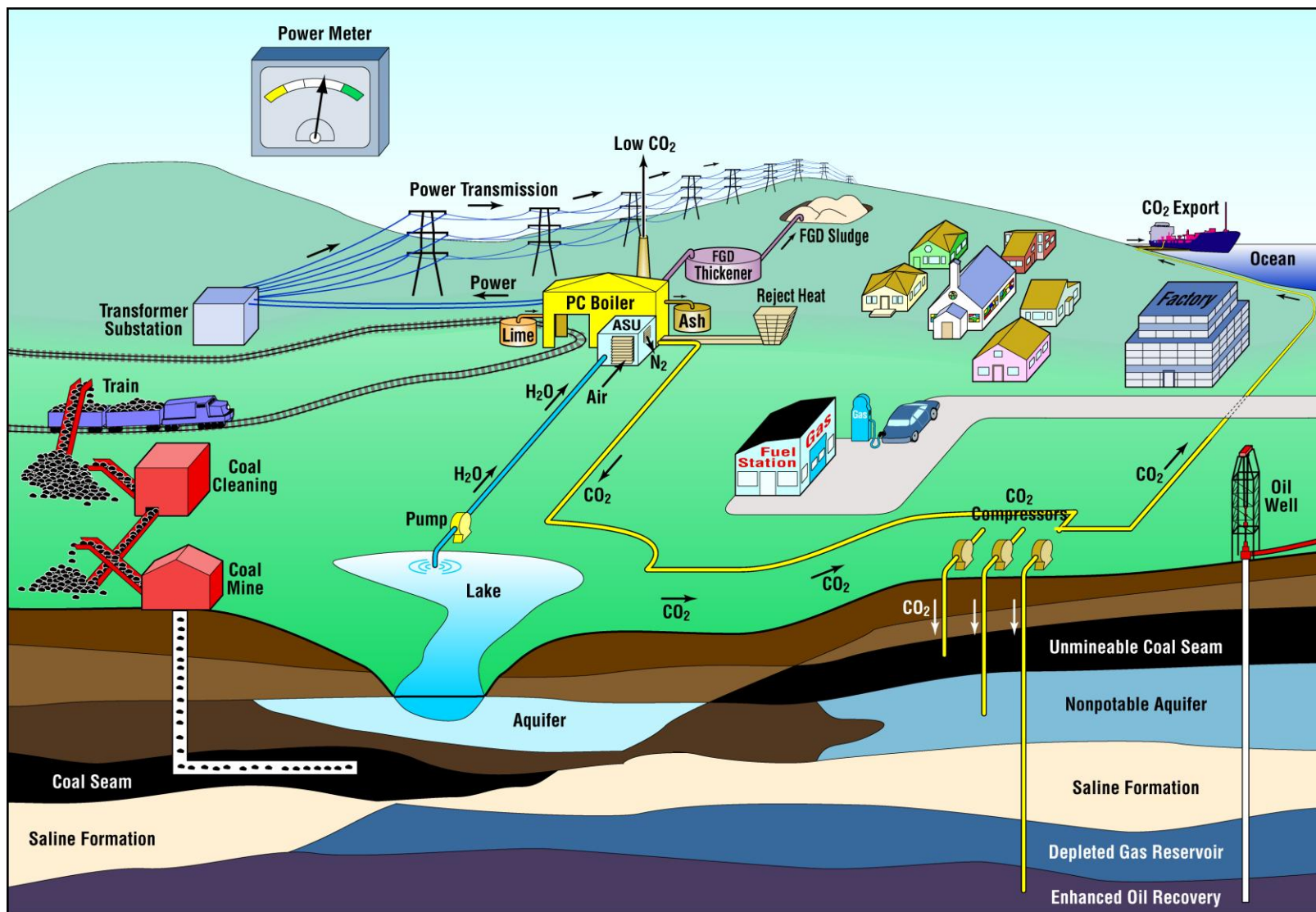
Approval Meeting in Montreal, 22-24 September 2005



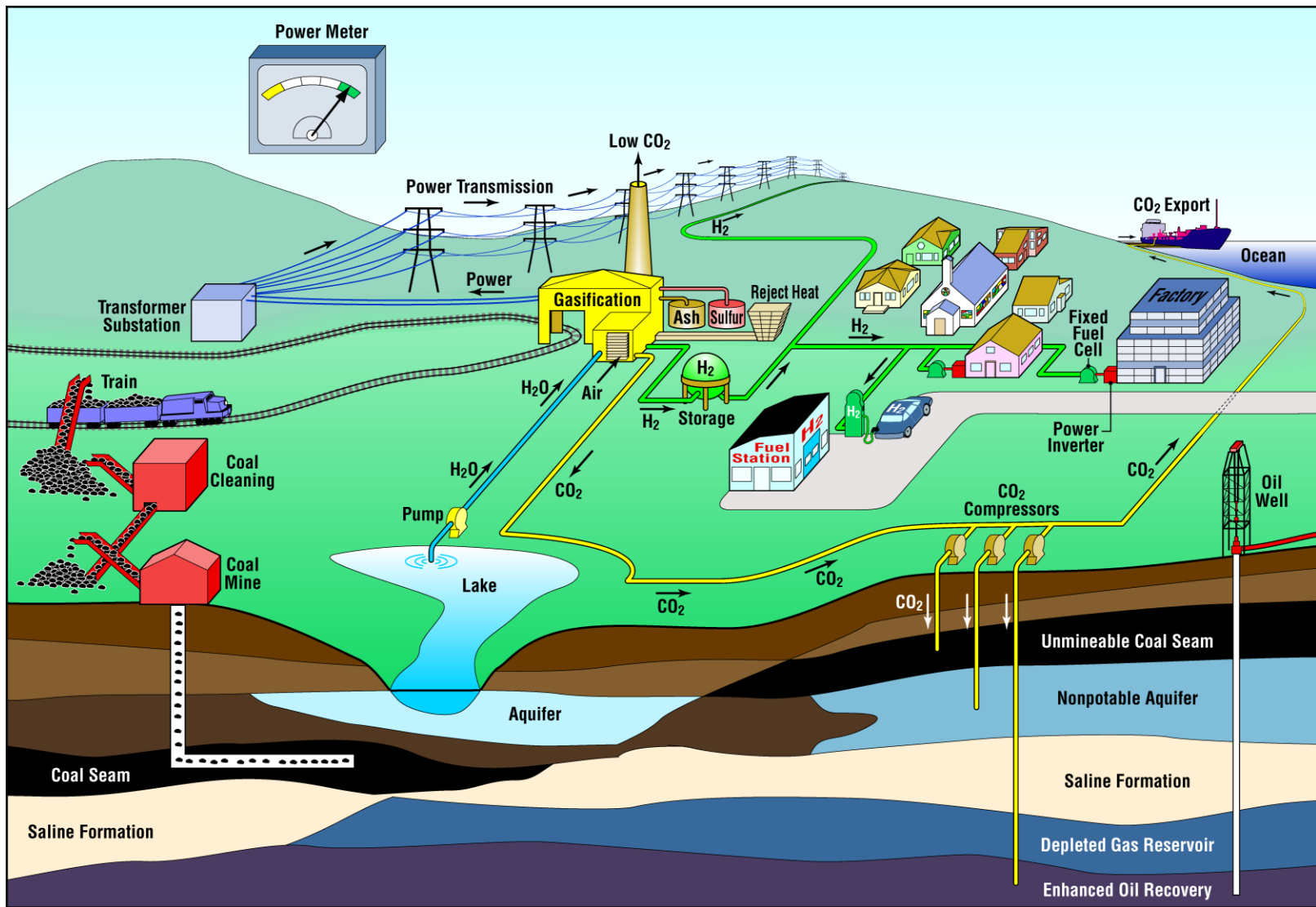
Pulverized Coal-fired Boiler



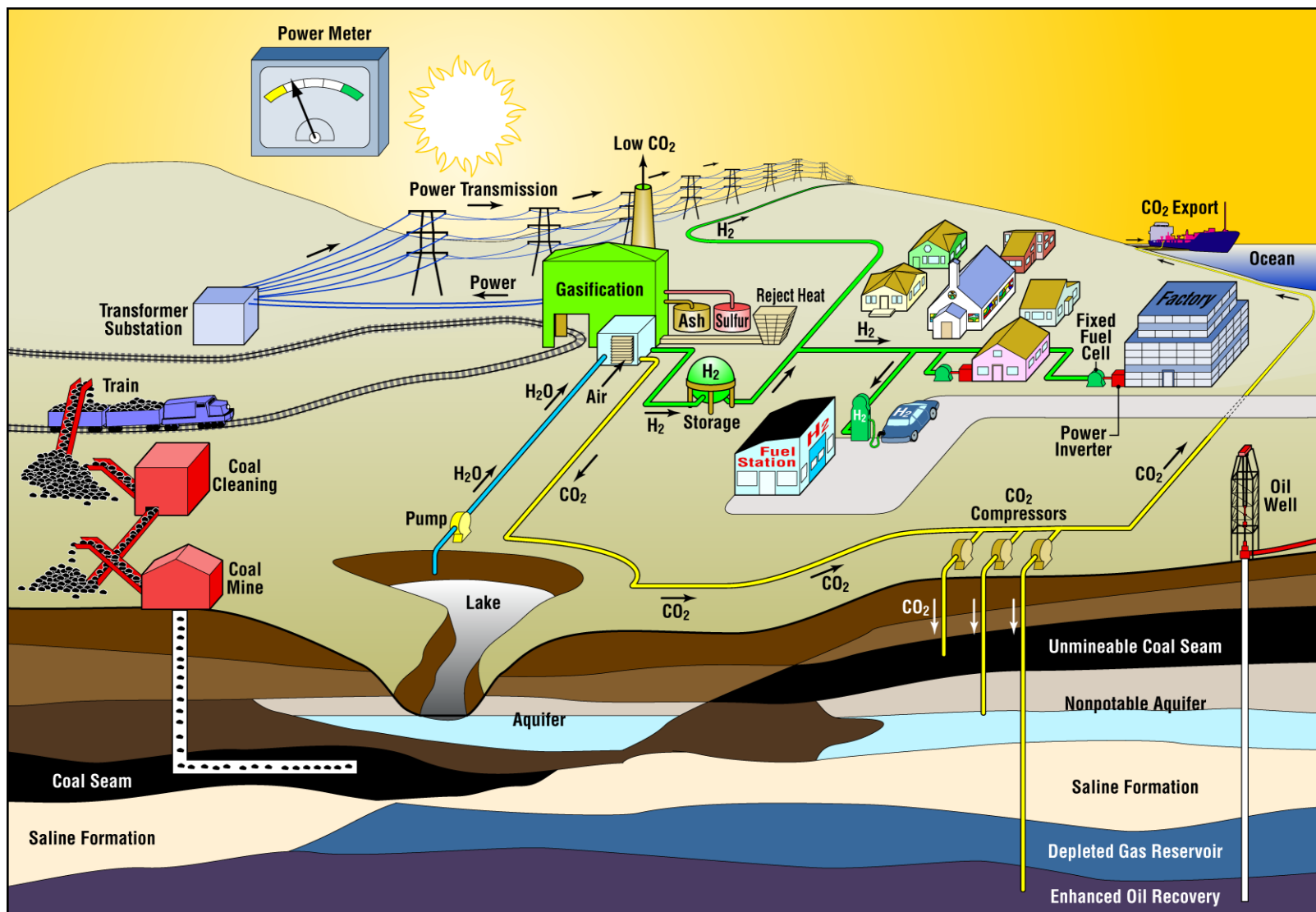
Pulverized Coal-fired Boiler – retrofitted for low CO₂



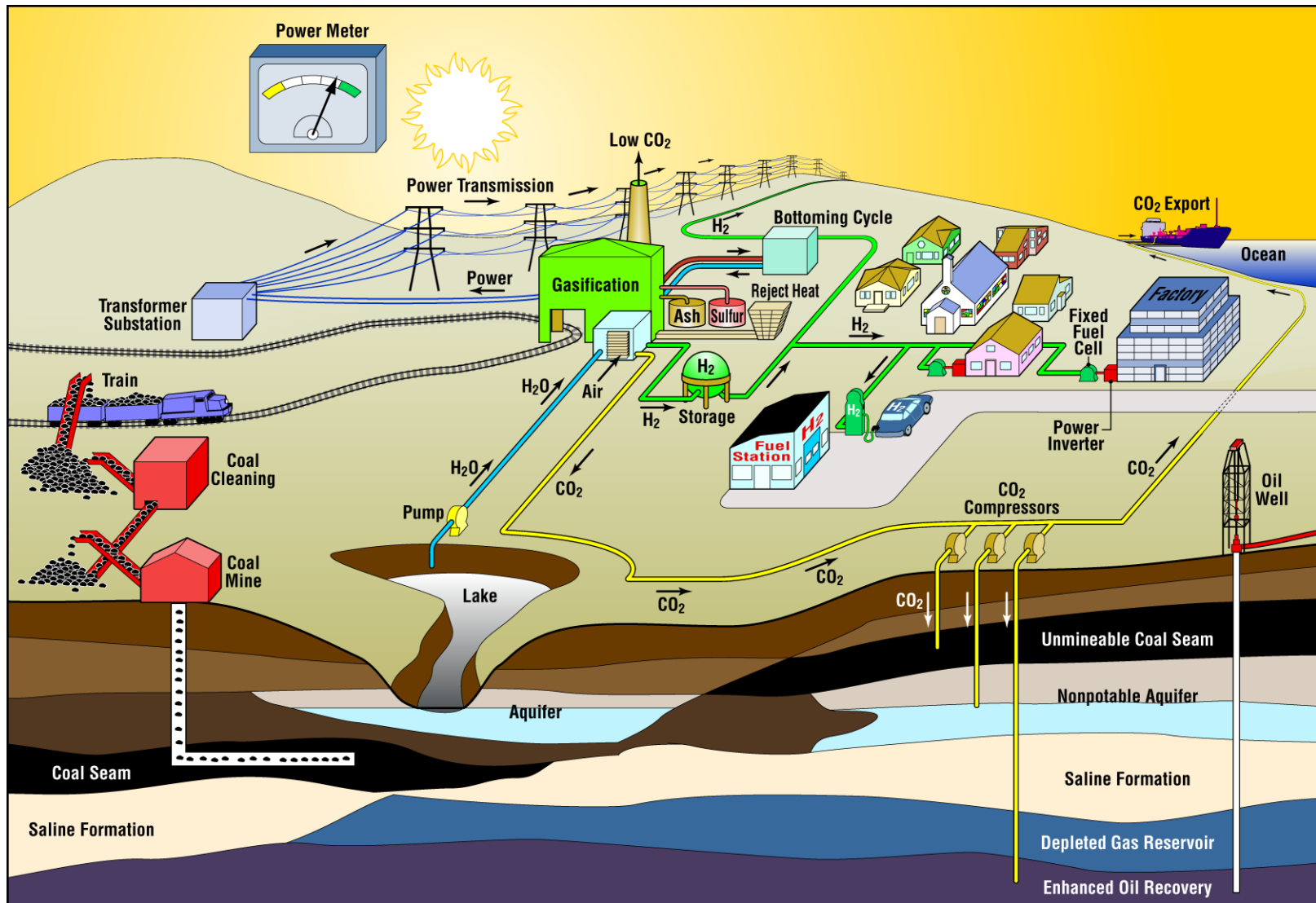
IGCC with multi-products including H_2



Future conditions may create novel design issues



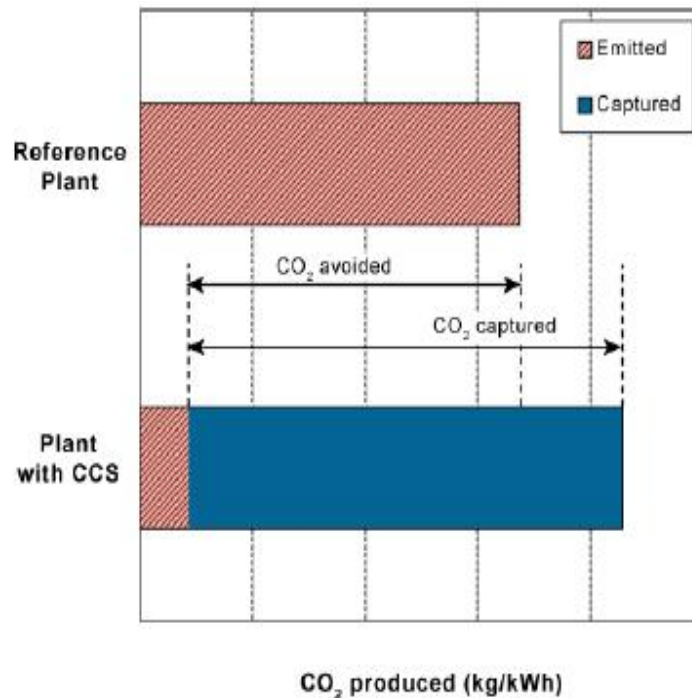
Water use in power cycles may require novel approaches



Net reduction of emissions to the atmosphere through CCS

IPCC Special Report – Carbon Dioxide Capture & Storage, Cambridge (2006) www.ipcc.ch

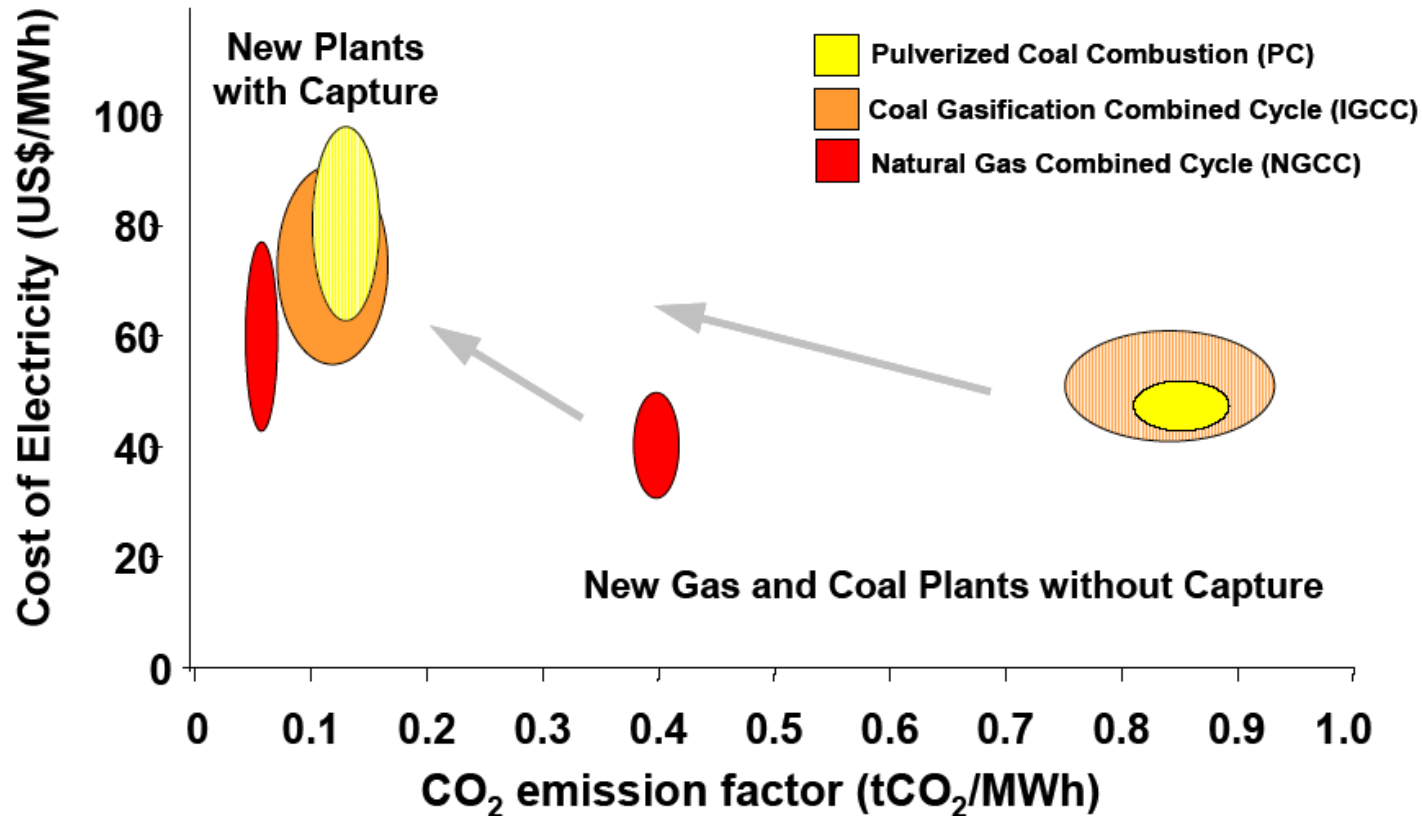
Net reduction of CO₂ captured must consider increased CO₂ production resulting from loss in efficiency due to the additional energy required for capture, transport and storage, any leakage from transport, and the fraction of CO₂ retained in storage.



Available technology captures about 85 - 95% of the CO₂ processed in a capture plant. A power plant equipped with a CCS system would need roughly 10 - 40% more energy than a plant of equivalent output without CCS, most of it for capture and compression.

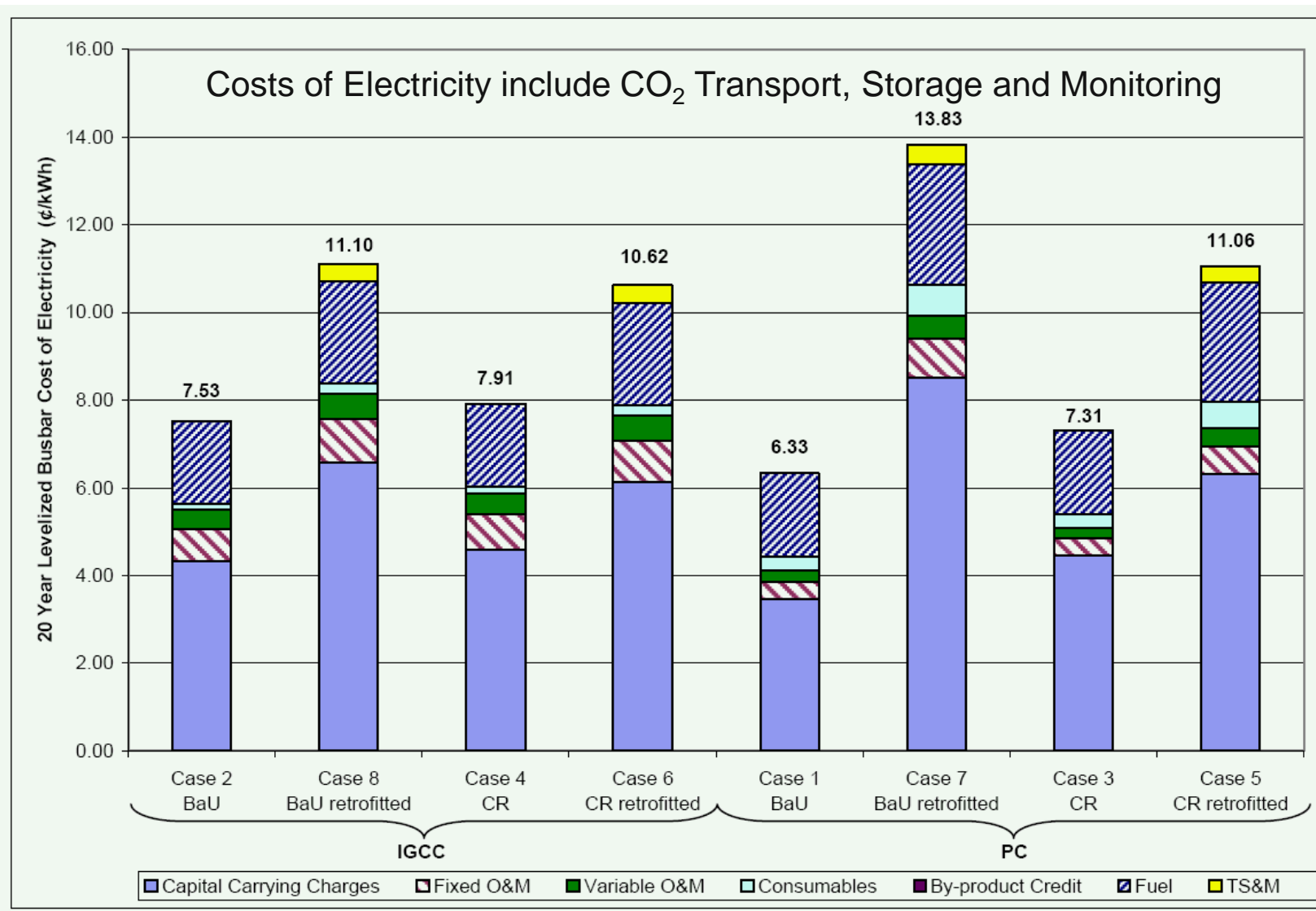
Significant emission factor reductions with Carbon Capture and Storage (CCS) comes with increased costs for electricity

IPCC Special Report – Carbon Dioxide Capture & Storage, Cambridge (2006) www.ipcc.ch



Costs of Electricity – Comparing IGCC and PC-boilers

CO₂ Capture-Ready Coal Power Plants, DOE/NETL- 2007/1301 (Final Report April 2008) NETL Contact: J. Ciferno



Capital Cost Summary – PC Boiler with CO₂ Capture

CO₂ Capture-Ready Coal Power Plants, DOE/NETL- 2007/1301 (Final Report April 2008) NETL Contact: J. Ciferno, p 84

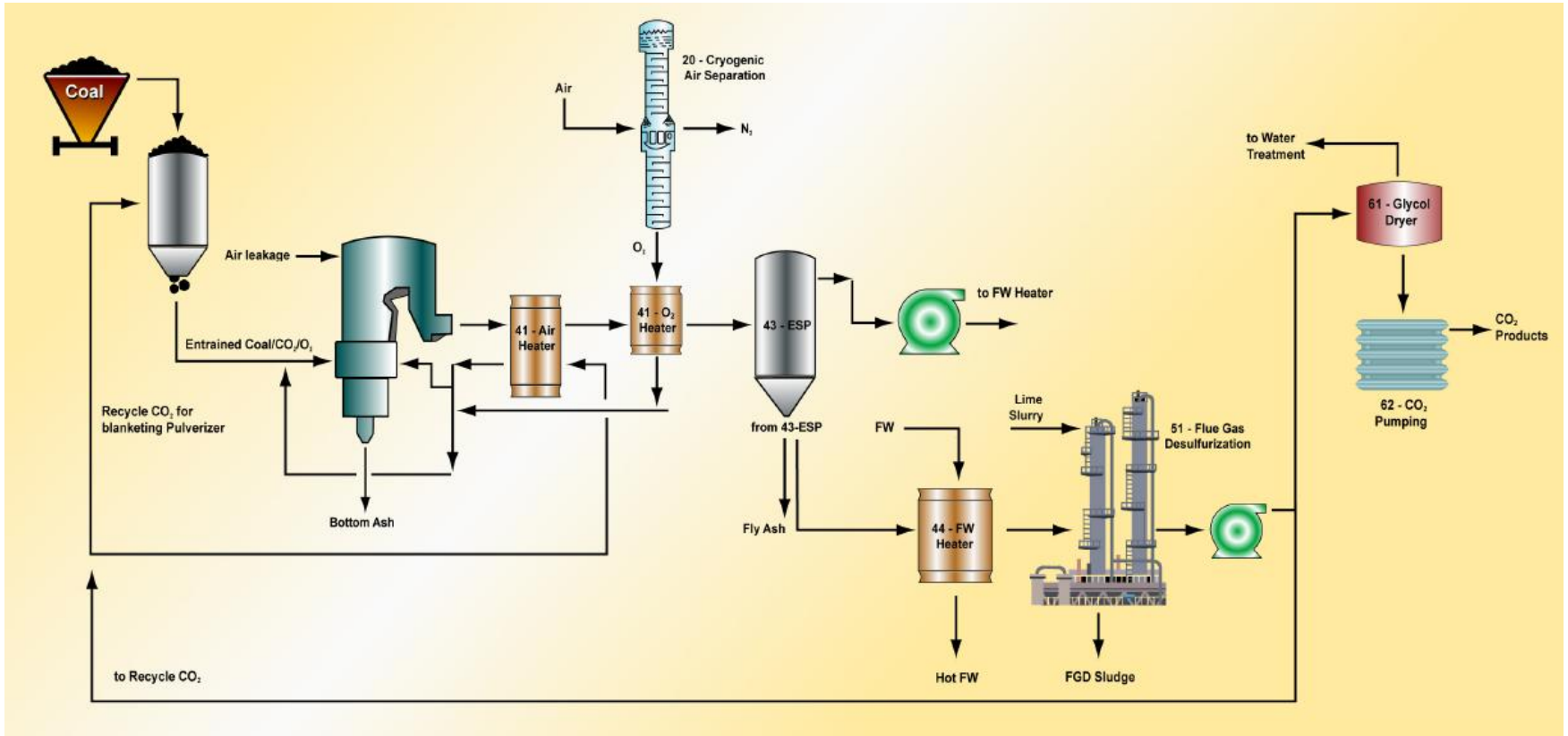
Client: U.S. DOE / NETL		Report Date: 02-Sep-07									
Project: Advanced CO2 Capture-Ready Power Plants											
TOTAL PLANT COST SUMMARY											
Case: Case 5 - Retrofit of 1x550 MWnet Capture ReadySuper-Critical PC w CO2 Capture											
Plant Size: 546.0 MWnet		Estimate Type: Conceptual		Cost Base Jan		2007		\$x1000			
Acct No.	Item/Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost \$	Eng'g CM H.O.& Fee	Contingencies		TOTAL PLANT COST	
				Direct	Indirect			Process	Project	\$	\$/kW
1	COAL HANDLING SYSTEM	19,316	5,215	11,691		\$36,222	3,246		5,920	\$45,389	83
2	COAL PREP & FEED SYSTEMS	13,126	758	3,326		\$17,210	1,508		2,808	\$21,527	39
3	FEEDWATER & MISC. BOP SYSTEMS	54,477		25,648		\$80,126	7,317		14,428	\$101,870	187
4	PC BOILER & ACCESSORIES										
4.1	PC Boiler & Accessories	190,969		107,678		\$298,647	28,927		32,757	\$360,332	660
4.2	SCR (w/4.1)										
4.3	Open										
4.4-4.9	Secondary Air System										
	Subtotal 4	190,969		107,678		\$298,647	28,927		32,757	\$360,332	660
5A	FLUE GAS CLEANUP	102,380		35,161		\$137,541	13,069		15,061	\$165,671	303
5B	CO2 REMOVAL & COMPRESSION	229,832		69,851		\$299,683	28,443	52,879	76,201	\$457,207	837
6	COMBUSTION TURBINE/ACCESSORIES										
6.1	Combustion Turbine Generator	N/A		N/A							
6.2-6.9	Combustion Turbine Accessories										
	Subtotal 6										
7	HRSG, DUCTING & STACK										
7.1	Heat Recovery Steam Generator	N/A		N/A							
7.2-7.9	Ductwork, Stack	17,889	981	12,221		\$31,091	2,840		4,457	\$38,388	70
	Subtotal 7	17,889	981	12,221		\$31,091	2,840		4,457	\$38,388	70
8	STEAM TURBINE GENERATOR										
8.1	Steam TG & Accessories	53,763		7,192		\$60,956	5,836		6,679	\$73,471	135
8.2-8.9	Turbine Plant Auxiliaries & Steam Piping	26,923	1,148	14,942		\$43,013	3,724		6,698	\$53,436	98
	Subtotal 8	80,687	1,148	22,134		\$103,969	9,561		13,377	\$126,907	232
9	COOLING WATER SYSTEM	21,479	11,200	19,881		\$52,559	4,900		7,796	\$65,255	120
10	ASH/SPENT SORBENT HANDLING SYS	5,154	162	6,854		\$12,169	1,158		1,371	\$14,699	27
11	ACCESSORY ELECTRIC PLANT	20,196	10,240	29,287		\$59,723	5,331		8,288	\$73,343	134
12	INSTRUMENTATION & CONTROL	9,195		9,662		\$18,857	1,726	943	2,648	\$24,174	44
13	IMPROVEMENTS TO SITE	3,162	1,818	6,421		\$11,402	1,120		2,504	\$15,026	28
14	BUILDINGS & STRUCTURES		23,760	22,735		\$46,495	4,189		7,603	\$58,287	107
TOTAL COST		\$767,862	\$55,282	\$382,550		\$1,205,695	\$113,335	\$53,822	\$195,221	\$1,568,073	\$2,872

Levelized Cost Summary – PC Boiler with CO₂ Capture

CO₂ Capture-Ready Coal Power Plants, DOE/NETL- 2007/1301 (Final Report April 2008) NETL Contact: J. Ciferno, p86

<u>PRODUCTION COST SUMMARY</u>		<u>Levelized Costs</u>
	<u>LF</u>	<u>¢/kWh</u>
Fixed O & M	1.162	0.62
Variable O & M	1.162	0.41
Consumables	1.162	0.60
By-product Credit	1.162	
Fuel	1.209	2.73
TOTAL PRODUCTION COST		4.36
<u>2007 CARRYING CHARGES (Capital)</u>		6.33
CCF for a 20-Year Levelization Period - IOU - Lower-Risk	16.4	
<u>20 YEAR LEVELIZED BUSBAR COST OF POWER</u>		10.69

CO₂ Capture for PC-Boilers using Oxy-Fuels – a Transitional Strategy



In 1985 Argonne initiated the world's first research on retrofitting boilers with flue gas recirculation (O₂-firing or Oxy-fuels) for CO₂ capture. This positions power stations for later repowering to IGCC since unlike other CO₂ capture major equipment such as Air-separation, CO₂ pumps and CO₂ pipelines transition nicely into a higher MW capacity IGCC retrofit.

CO₂ Capture for PC-Boilers Using Oxy-Fuels – a Transitional Strategy

- Retrofitting boilers with flue gas recirculation (O₂-firing or Oxy-fuels) as a strategy for CO₂ recovery from conventional pulverized coal fired boilers is a technically feasible *transitional strategy* for lowering greenhouse gas emissions
- A molar ratio of CO₂/O₂ of ~3 is necessary to preserve the heat transfer performance and gas path temperatures, allowing this system to be applied as a retrofit
- Several studies have shown that Oxyfuels are competitive against CO₂ amine-capture and recovery. [See Doctor, Molburg, et al, “CO₂ Capture for PC-Boilers Using OXY-FUELS – A Transition Strategy,” GHGT-7 (Sept. 2004)]
- Results from ASPEN+ for 3 plant sizes with 3 coals

Oxyfuels retrofit to PC-boiler Pulverized Coal

Oxycombustion Power Plants, DOE/NETL-2007/1291 (Final Report August 2007) NETL Contact: J. Ciferno

		Supercritical		
CO ₂ Capture		No	95% Oxyfuel	99% Oxyfuel
Report Case Number →		1	5	5C
Capital (\$/kW)	Base Plant	1,335	1,893	1,912
	Air Separation Unit	-	509	511
	Flue Gas Cleanup	228	318	319
	CO ₂ Capture/Comp.	-	210	282
Power Plant Capital (\$/kW)		1,563	2,930	3,024
Capital COE (¢/kWh)		3.44	6.89	7.11
Production COE (¢/kWh)		2.85	4.01	4.06
Total Plant COE (¢/kWh)		6.29	10.90	11.16
Including Transportation and Storage				
Total COE (¢/kWh)		6.29	11.30	11.54
Incremental COE (¢/kWh) ^a		-	5.01	5.28
Increase in COE (%) ^a		-	80	83
\$/ton CO ₂ Avoided ^a		-	57	60
^a Compared to Case 1—Supercritical PC w/o CO ₂ capture				

Site-specific 300 MW Oxyfuel vs. Amine retrofit advantages for IGCC repowering

Doctor, Molburg, et al, "CO₂ Capture for PC-Boilers Using OXY-FUELS – A Transition Strategy," GHGT-7 (Sept. 2004)

Green highlights – equipment that will retrofit for IGCC

	Oxy-fuel	Amine (MEA)
Air Separation Unit	\$101,000	
Amine Scrubber		\$67,992
Ducts/Dampers/Air heaters/Controls	\$2,571	\$1,697
Feed water Heater	\$395	
O2 Heater	\$193	
Seal Boiler for 1% in-leakage	\$22	
Cooling Towers/Cooling Pumps		\$35,790
Flue Gas Desulfurization/Caustic	\$6,317	\$8,423
Chemical Treatment		\$8,949
CO2 Conditioning and Compression	\$36,828	\$33,145
TOTAL DIRECT COSTS	\$147,326	\$155,995
RETROFIT CAPABLE for IGCC	\$137,828	\$68,935

CO₂ Pipeline Specification will drive design

Acid gas experience shows that up to 45% H₂S is practical

U.S. Quality Specifications for CO₂ – KinderMorgan

CO ₂	95%	Min	MMP Concern
Nitrogen	4%	Max	MMP Concern
Hydrocarbons	5%	Max	MMP Concern
Water	30 lbs/MMcf	Max	Corrosion
Oxygen	10 ppm	Max	Corrosion
H ₂ S (Sulfur)	10 – 200 ppm	Max	Safety
Glycol	0.3 gal/MMcf	Max	Operations
Temperature	120 deg F	Max	Materials

- **MMP – minimum miscibility pressure for EOR use only**

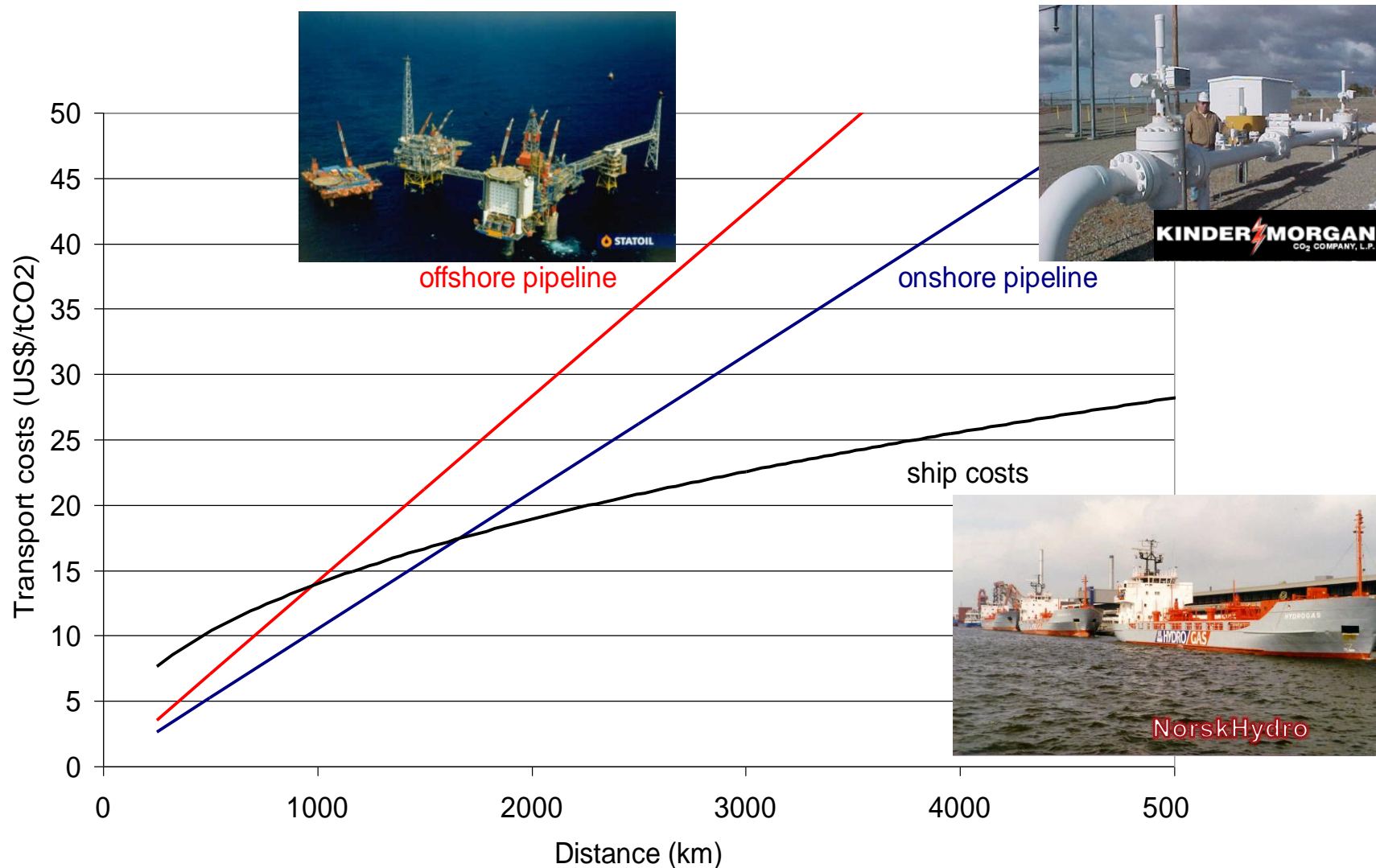
Frequent recycling leads to unacceptable acid-gas build-ups

- Carroll and Maddocks (Oil & Gas Journal 1999) caution:

‘Recently some have investigated the value of using compressed acid gas as a part of a miscible flood scheme. We would recommend against such a scheme because it will lead to a build-up of acid gas and ultimately an increased load on the amine unit.’

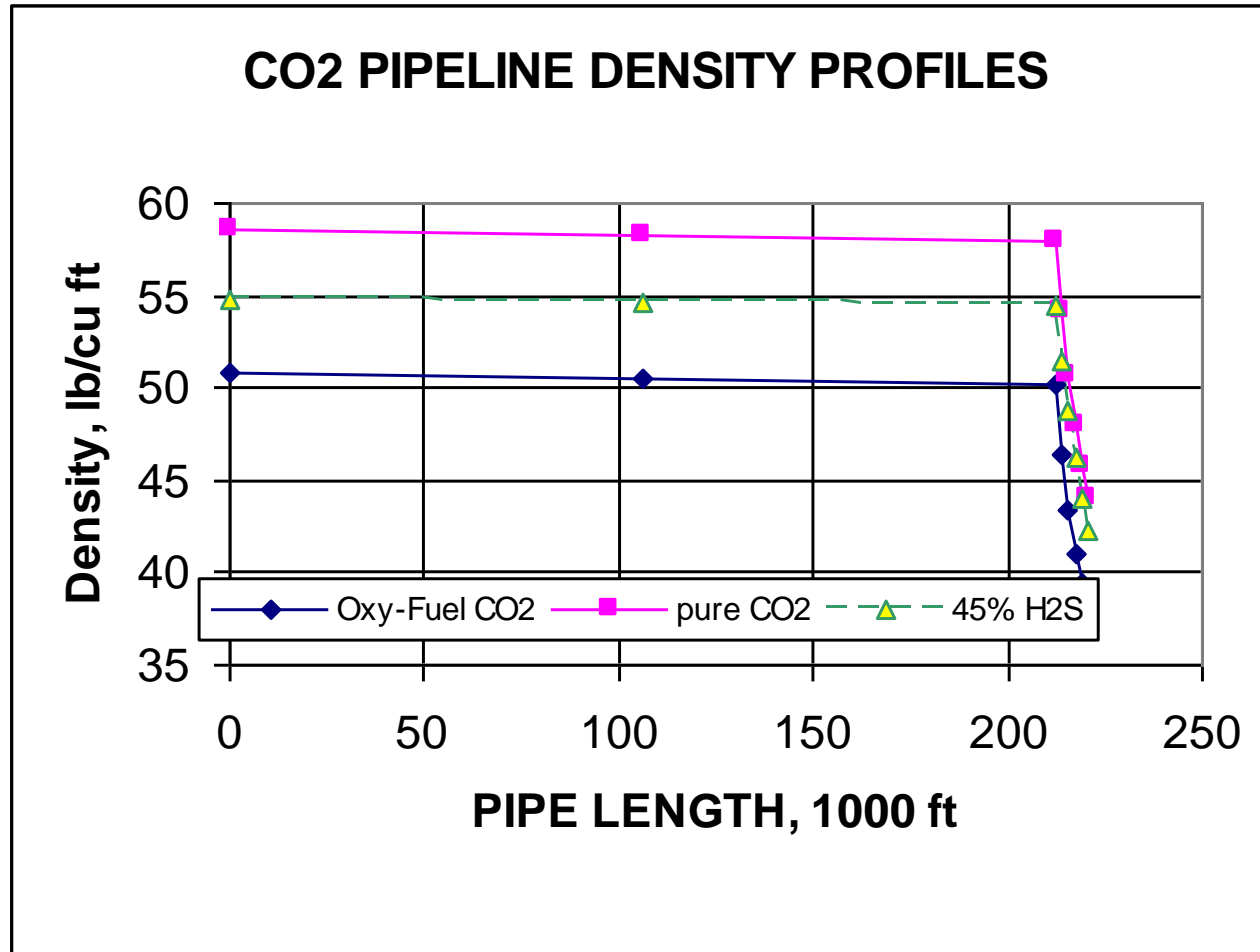
Pipelines are preferred for transporting CO₂ but ships could be economically attractive

IPCC Special Report – Carbon Dioxide Capture & Storage (Cambridge 2006)



Inerts (N_2 , Ar) and impurity gases may need to be removed for economic reasons – Peng-Robinson-Boston-Mathias Equation of State CO_2 injection at well

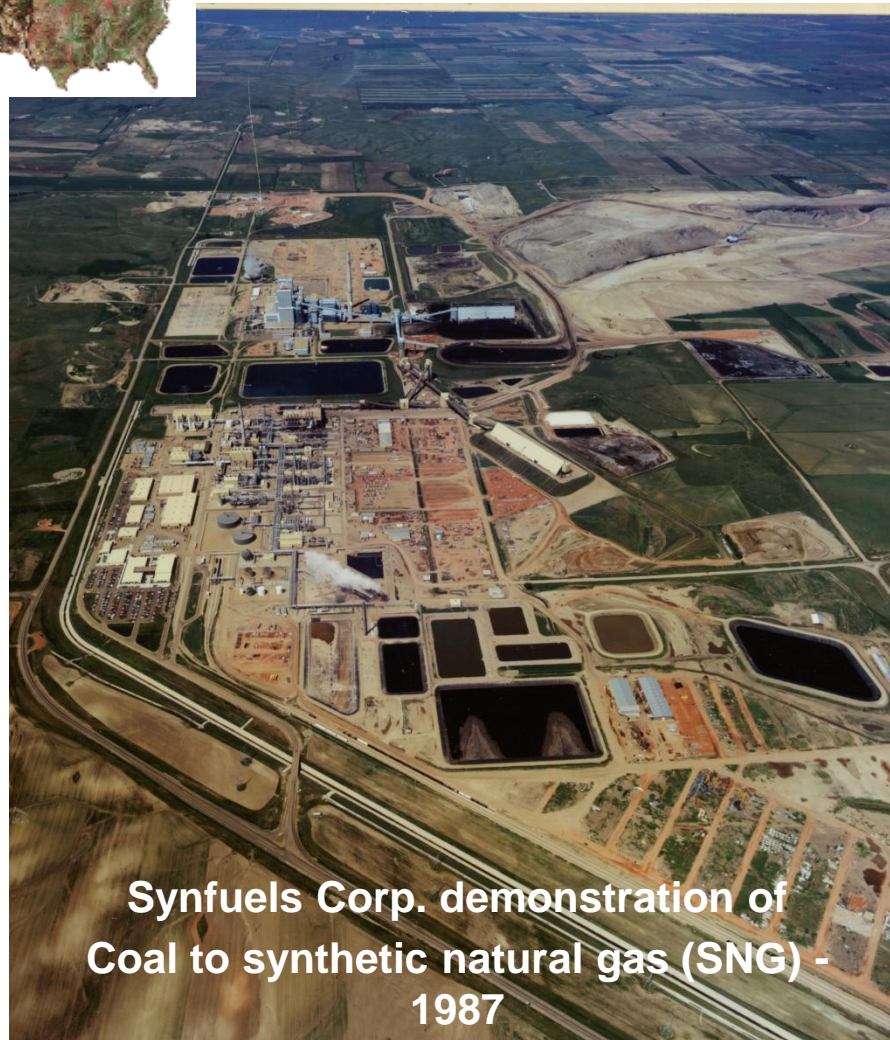
Brockmeier, N.F., J. Kim, and R.D. Doctor, "Prediction of Physical Properties of Trans-Critical CO_2 Gas Mixtures, Greenhouse Gas Technologies," Proceedings of the 7th International Conference, Elsevier (2005)



CO₂ sequestration is used at the Basin Electric Cooperative Dakota Gasification Project (Great Plains – Coal to CH₄)

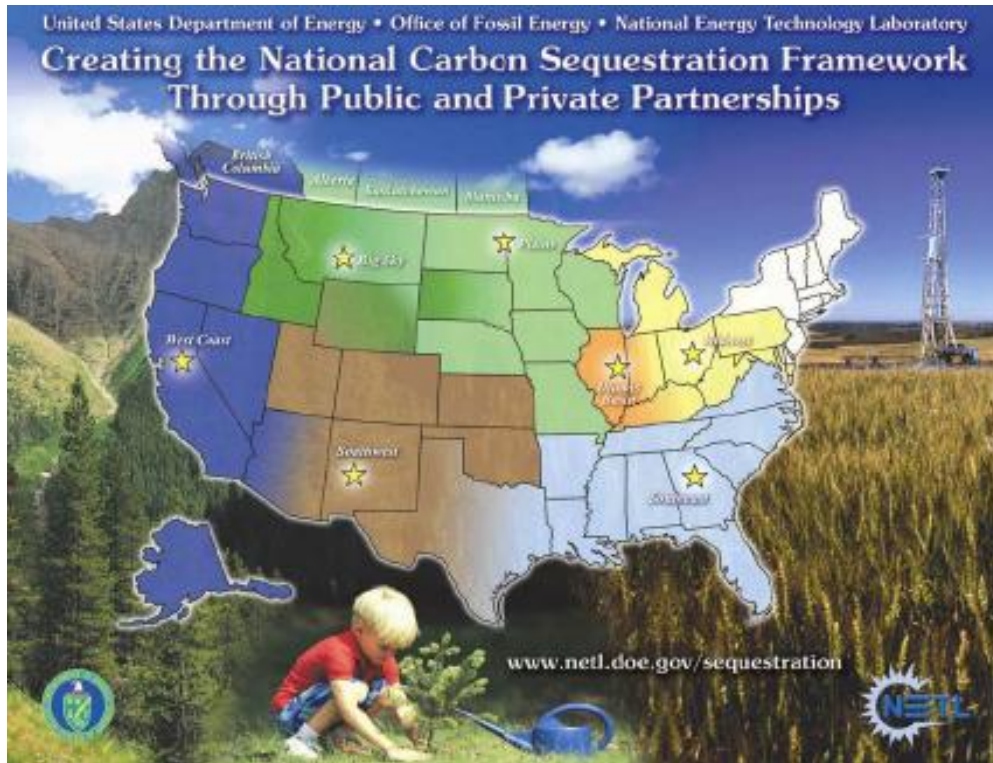


- Lurgi coal gasification for a \$2.2 Billion (1985) project design for 63% efficiency – *entrained flow gasifiers now dominate the market*
- Feed 14,000 tonnes/day lignite produces 3.8×10^6 n-m³/day CH₄
- H₂ production= 541 tonnes/day ~13,000 Barrels/day gasoline equivalent
- Recovery of CO₂=4,400 tonne/d for use 340 km away at the PanCanadian Weyburn field EOR project
- **A new 10-British Lurgi Gasifier plant announced April 2008**



Synfuels Corp. demonstration of Coal to synthetic natural gas (SNG) - 1987

US Response – Phase 1 set up Regional Public-Private Partnerships for Carbon Capture and Sequestration

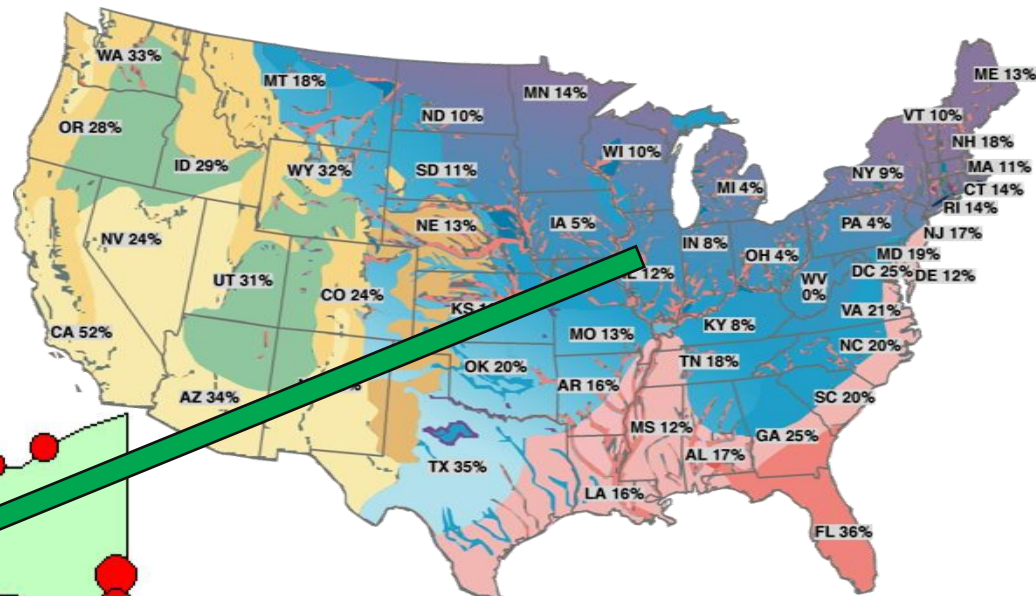


www.netl.doe.gov/technologies/carbon_seq

Partnerships as of June 2005 have:

1. Established a national network of companies working to support CCS
2. Created a carbon sequestration atlas for the United States
3. Obtained an improved understanding of the permitting requirements for CCS
4. Raised awareness and support for carbon sequestration as a greenhouse gas mitigation option, both within industry and the general public
5. Identified priority opportunities for sequestration field tests
6. Established protocols for project implementation

Non-Independent Power Stations for Illinois, Indiana and Ohio – 300 MW and larger



Water stress – Population Growth

Less Water

More Water

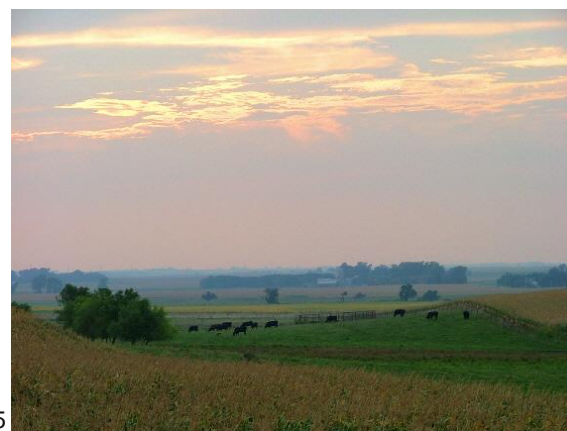
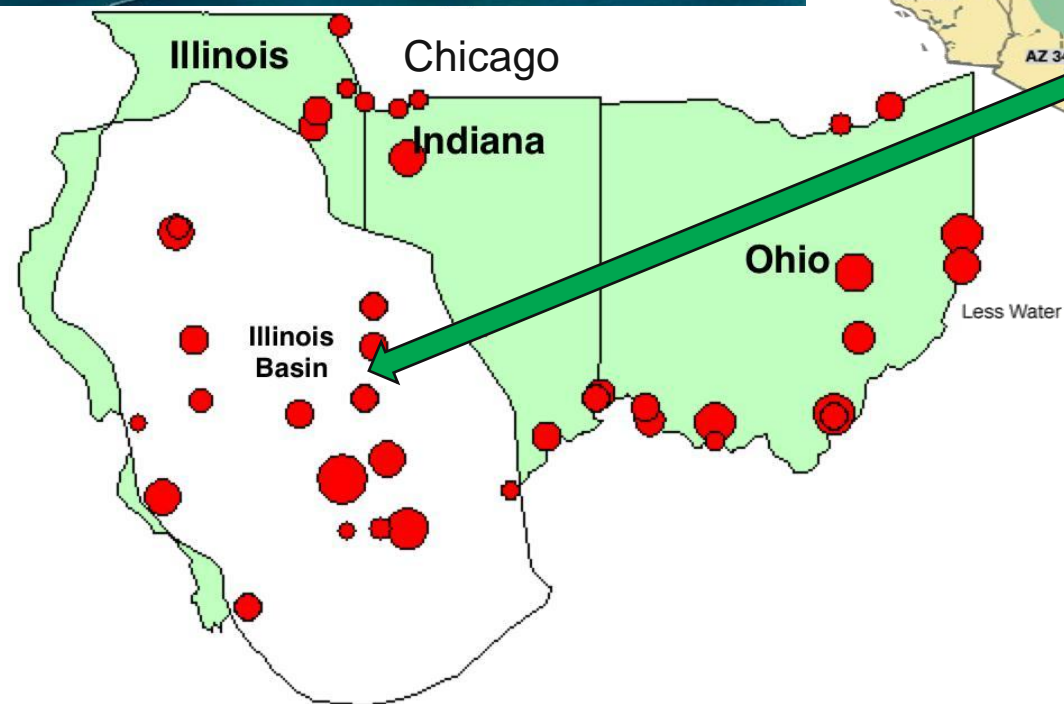


PHOTO – LYNN WILLIAMS 11-SEP-2005

Where is Carbon Capture Sequestration CCS right now?

CO₂ for Enhanced Oil Recovery now uses ~2,500 km of pipelines operating safely since the mid-1970s

U.S. Department of Energy Partnerships for CCS - Phase 2 just awarded the first 3 large-scale projects — Total \$318 Million

October 9, 2007

Regulatory work continues.

The National Carbon Sequestration Database and Geographical Information System (NATCARB) and the National Energy Technology Laboratory (NETL) created a methodology to determine the capacity for CO₂ storage in the United States and Canada, and an Atlas from data generated by the Partners. Information collected during Phase 2 Validation will be used to update the CO₂ storage capacity estimates throughout the U.S., to revise and issue an updated version of the Atlas in 2009.

*In Conclusion CCS is a
“Work in Progress”*

